Case Study No. 1: ATCO Structures & Logistics

Report No 1: Identify the strategies to enhance the economic and environmental performance of projects using products with recycled and recyclable content (Case Study No. 1: ATCO Structures & Logistics)

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Research Project: Project 1.95 Using recycled and recyclable products: Influencing stakeholders through circular economy practices

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Executive Summary

Modular construction is a building method where individual components, or modules, are prefabricated in a factory-controlled environment and then transported to the construction site. These modules are typically designed to fit together seamlessly to form a complete structure, such as a home or commercial building. The use of secondary materials in modular construction is a sustainable strategy to enhance products with recycled content (PwRC) uptake in the building and construction sector. The factory setting allows for greater exploration and application of eco-friendly materials, which may be challenging to implement in conventional construction environments. This report provides the findings of a literature review and a case study (ATCO Structures and Logistics) that provides insight into the use of PwRC in modular construction.

First, the research team conducted an extensive literature review to highlight the status of modular construction uptake in Australia (Section 3.1) and explore the main drivers (Section 3.2) and challenges 3.2(Section 3.3) to enhance its uptake in the Australian context. This review also identified the major environmental and economic benefits of using PwRC in modular construction in Australia (Sections 3.4 and 3.5).

Second, the findings from the case study analysis, which was based on a series of interviews with the six key stakeholders involved in various activities related to modular construction, are presented. The aim of this case study was to understand the main challenges, motivations, strategies and benefits of PwRC utilisation in modular construction. The results showed that there are 16 categories of challenges that hinder the application of PwRC in modular construction. These categories include a broad range of issues, including supply chain, cost, organisational limitations and technical complexities. The analysis of motivations revealed that 'supportive organisational targets', 'financial benefits', 'client preference and obligations', 'securing public projects' and 'moral obligations' can drive the use of these resources in modular construction. The interviews also revealed that ten strategies could further enhance the adoption of PwRC in modular construction.

Lastly, according to the research findings, this report provides a framework developed to guide efforts in enhancing the uptake of PwRC in modular construction. This framework consists of four components that propose strategies to enhance organisational capacity, supply chain performance and recycled product quality as well as policies that can support this transformation across the first three components.

TABLE OF CONTENTS

List of Tables

List of Figures

1 INTRODUCTION

Modular construction is a building method where individual components, or modules, are prefabricated in a factory-controlled environment and then transported to the construction site. These modules are typically designed to fit together seamlessly to form a complete structure, such as a home or commercial building. Modular construction comes in several forms. It can be delivered "as a box" in finished form, as a flat pack – separate parts such as wall frames and floor panels – or as a kit of smaller components.

Prefabrication is revolutionising the construction sector at every level by bridging construction and manufacturing. This concept is encapsulated in the definition of industrialised construction, which involves the prefabrication, modularisation, and standardisation of construction processes and assets in controlled factory environments[1].

Modular construction has the potential to also transform project management for construction firms, with onsite construction projects completed in as little as 12 weeks instead of the traditional 12-month timeline. Additionally, modular design enhances their ability to handle multiple projects simultaneously without compromising quality or risking damage to their reputation. The use of modular construction provides several benefits as outlined in Table 1. These advantages encompass social, environmental, and economic aspects, offering a more sustainable construction approach overall.

In modular construction, bulk material orders allow manufacturers to fabricate multiple modules simultaneously, leading to lower prices from suppliers and reduced labour and transportation needs. This results in cost and time savings for the project. Additionally, prefabricated construction reduces the on-site labour force, lowering total labour costs by approximately 25% compared to traditional methods; this is specifically evidenced when labour force has to be deployed in regional areas. It is well documented that when construction phase activities overlap with prefabricated construction, there is a reduction in construction time of approximately 40% compared to traditional construction methods[2]. One study focused on dwellings only, indicates that modular construction can cut construction times by as much as 50% and reduce costs by up to 20%[3]. Another analysis estimates claimed offsite construction is three times more productive than onsite[1].

Another key benefit is the immunity to weather disruptions, allowing for year-round production and the potential for multiple shifts, leading to optimal utilisation of plant and equipment. This high utilisation rate helps justify investments in new modular technologies. Furthermore, the controlled factory environment enhances safety, resulting in fewer days lost to injuries compared to onsite construction. Offsite construction also enables concurrent work processes, such as foundation and wall construction, which can then be integrated onsite. Additionally, the use of digital technologies is more extensive in a factory setting, providing greater precision in cost estimation and delivery times. Process control technologies and automation reduce time and waste, leading to fewer defects and the need for rework[4]. In terms of construction work safety, the adoption of this technology can provide a safer working environment which can result in the reduction of safety incidents by up to 80%[5].

This type of construction also offers environmental advantages, including decreased construction waste and CO_2 emissions, as well as reduced disturbance to neighbouring sites by minimising on-site noise and dust pollution. A recent report by the Waste & Resources Action Program (WRAP) shows

[1] KPMG (2016) Smart Construction – How offsite manufacturing can transform our industry. Available from https://bit.ly/3Zu52dk

[2] Navaratnam S, Ngo T, Gunawardena T, Henderson D (2019) performance review of prefabricated building systems and future research in Australia. *Buildings*. 2019; 9(2):38. https://doi.org/10.3390/buildings9020038

[3] Bertram N, Fuchs S, Mischke J, Plater R, Strube G and J Woetzel (2019) Modern Construction: From Projects to Products. McKinsey & Company. Available from https://bit.ly/4edwrEU

[4] PrefabAus (2023). Australia's Smart Building Revolution: A Prefabrication Industry Roadmap 2023-2033.

[5] Lawson, R.M.; Ogden, R.G.; Bergin, R. (2012) Application of modular construction in high-rise buildings. *Journal of Architectural Engineering*. 18, 148–154

that a 90% of waste reduction can be obtained by optimising the use of off-site construction[6]. Roughly similar figures were found in a case study[7] conducted in Australia. The authors of this case study inferred that there is an inversely proportional relationship between the level of prefabrication and waste generation.

[6] Meyers, M (2016) How modular construction is keeping waste out of U.S. landfills. 3P Contributor. Available from https://bit.ly/4gCbDZJ
[7] Loizou L, Barati K, Shen X, and B Lit (2021) Quantifying advantages of modular construction: waste generation. *Buildings*. 11, 622.

Table 1. Summary of the major advantages and disadvantages of modular construction

	Advantages	Description	Disadvantages	Description
Economic benefits	1. Faster construction	Modular construction involves simultaneous off-site fabrication and on-site foundation work, reducing overall construction time	Transportation costs	Shipping large modules to the site can be expensive
	2. Cost-effective (affordable)	Prefabricated modules are produced in a controlled environment which may result in reducing labour and material costs. Furthermore, with a wide range of designs and inclusions, the final cost of the project may be lower than expected, depending on the contextual factors.	Limited customisation	Modular designs often have limitations in terms of architectural creativity and flexibility due to the predetermined transportation height/width limitations
	3. Improved construction quality	Factory-controlled construction ensures higher quality control compared to traditional on-site construction. DfMA advantages are exploited for subassemblies reducing errors and quality hold points	Dependency on factory production and limitations on the material selections	Delays in the factory can lead to project delays
Socio-environmental benefits	1. Less disturbance to building site local residents' everyday lives	Less disturbance to the building site's neighbours by minimising on-site noise and dust pollution and project completion time	Size limitations	Restrictions on the dimensions of a prefabricated structure might exist due to regulations concerning the width of roads allowable for transportation.
	2. Reduced material waste	Precise manufacturing processes minimise waste or reuse/repurpose waste that would otherwise be disposed of	Potential for damage	Modules can be susceptible to damage during transportation and installation
	3. Safer working conditions	With much of the construction work done off-site, on-site workers are exposed to fewer hazards and other conditions such as weather, ground or crew politics	Requires skilled labour	Specialised skills & expertise are needed for module fabrication and on-site assembly and commissioning
	4. Post-disaster housing management	Rapid deployment of housing units to areas affected by disasters, providing quick and efficient temporary housing solutions for displaced individuals and communities	High running costs	It requires high investment costs as well as additional project planning

However, this construction technology comes with some limitations. As outlined in Table 1, there are seven primary limitations in modular construction, and these can multiply if modular construction organisations fail to adopt best management practices. Limitations exist at various stages of off-site construction, from planning and design to manufacturing and installation. This is inherent in all construction and not unique to modular construction however forward planning is strategically important as there is little time to figure out issues in this form of construction.

The use of secondary materials in modular construction is a sustainable strategy to enhance PwRC uptake in the building and construction sector. The factory setting allows for greater exploration and application of eco-friendly materials, which may be challenging to implement in conventional construction environments. The following sections explore the research approach employed in this study and provide an overview of the application of PwRC in modular construction.

2 RESEARCH APPROACH

2.1 Review of literature

This section of the report presents the research approach employed. First, the research team conducted an extensive literature review to offer insight into the status of modular construction uptake in Australia (3.1) and explore the main drivers (3.2) and challenges 3.2Section 3.3) to enhance its uptake in the Australian context. This review also identified the benefits of using PwRC in modular construction in Australia (3.4 and 3.5). The sources used in this step included journal articles and government and industry reports that are freely available online. Care was taken to only capture the literature that describes the use of PwRC in recent years to reflect the contemporary efforts and advances in using these materials.

2.2 Case study

In the second step, a case study analysis was conducted to understand Australians' experience in using PwRC in modular construction. In consultation with the project partners and waste experts, the criteria for the selection of the case study were set. The case study had to meet the following criteria:

- *Use of PwRC in modular construction;*
- *Its recent application in the organisation projects*
- *Ease of access to key stakeholders*

After identifying the project, ATCO Structures & Logistics, the perceptions of key stakeholder groups playing an essential role in using PwRC were sought through conducting a series of interviews. The interviewees were selected in consultation with the ATCO S&L sustainability team. An invitation email was sent to each stakeholder to arrange suitable interview times.

The online interviews were conducted between March 2024 and April 2024 using the Microsoft Teams online platform. Each interview took a maximum of one hour and was recorded for transcription purposes. Three types of questions were asked during interviews: participants' details, their experience using the PwRC modular construction, and the enablers of and barriers to using such resources in this section of the industry. Table 2 provides the full interview questions:

Table 2. Interview questions used in the case study analysis

No	Question
1	Please introduce yourself, including your employment history and recent activities in the field of construction and demolition (C&D) waste management.
2	Can you please tell me a bit about the project and your respective involvement?
3	Can you please tell me about your organisation's experience using products with recycled content in this project?
4	What is the process of procuring waste materials and repurposing them into usable products in your organisation?
5	What were your main motives for using recycled content in ATCO products?
6	What are the main five challenges to using recycled content in ATCO products?
7	In your opinion, how could these challenges (and their impact) be overcome?
8	What specific benefits and challenges arise from using modular construction for incorporating recycled materials?

9	What are the primary social, environmental, and economic advantages of utilizing recycled materials in modular construction?
10	How do you see the future of the application of recycled materials in modular construction in Australia?
11	Has your organisation published any relevant documents describing the project planning, design and execution that you could share with us?

2.3 Data analysis

The data extracted from the literature review was thematically analysed preceding the creation of the major clusters of benefits, challenges and barriers to using PwRC in modular construction projects in Australia. The literature analysis provided the basis for a case study analysis in the Australian construction industry.

Audio data captured from 6 interviewees were carefully transcribed by a professional transcriber using the word-for-word method prior to the quality verification of the text data by the research team. The transcripts were analysed using the NVivo Pro 12 application, which facilitates codifying text-based qualitative data. A thematic analysis method was applied to identify emerging themes that were related to the three research objectives. Furthermore, to better compare the qualitative data, quantitative descriptive analysis methods were adopted. The frequency of distribution of various categories of factors identified in the interviews was the main statistical measure used to conduct these comparisons.

3 LITERATURE REVIEW

Modular construction offers a wide range of environmental and economic benefits. This section of the report reviews these benefits in light of the use of PwRC and waste minimisation during their application.

3.1 Modular construction in Australia: An overview

All modern methods of construction (MMC) approaches particularly modular construction are experiencing a surge in popularity in Australia due to recognised value as an efficient construction method. As outlined before, this approach reduces overall construction costs, saves time, and encourages innovation.

With less than 5% of the total construction, the adoption of modular construction in Australia lags behind that of many other advanced economies[4], such as Scandinavian countries, Japan, Singapore and Germany. The PrefabAus industry roadmap report indicates that by 2025, this figure will reach 15%. While modular design may not be the perfect solution to address all the challenges in the Australian housing market, it does represent an initial step toward a fairer housing solution. One may consider the potential of high-quality buildings that can be disassembled, moved, and updated easily in a community that greatly needs more affordable housing options[8]. Furthermore, Australia boasts the largest average home size globally. However, modular housing, akin to the tiny homes' movement, promotes the idea of living with a smaller footprint.

The public sector's capital expenditure is expected to increase by 2.8% in 2023-24, leading to a rise in demand for prefabricated building products such as sheds, industrial facilities, and temporary warehouses. This growth is driven by major infrastructure projects like the Western Sydney Infrastructure Plan, Perth's METRONET expansion, and the Victorian Government's Metro[9]. Federal and State governments across the nation are increasingly showing significant interest in modular construction. For instance, the Department of Foreign Affairs and Trade (DFAT) requires the use of modular building solutions for replacing assets in the Pacific Islands, as well as for critical consular and diplomatic facilities. Acknowledging the security benefits of offsite construction, the Australian modular construction industry has supplied the majority of construction needs for the Australian Defence Forces over the past decade[4].

At the state level, Queensland is committed to extending its apprentice-led QBuild program, producing prefabricated homes in a Brisbane factory. Australian prefabrication supplies 80% of the build for the 2032 Queensland Olympic Games athletes' village. Correctional Services NSW has pledged to boost the production of modular homes by June 2025, aiming to enhance the supply of Indigenous housing. Meanwhile, in Victoria, the state government has started providing modular housing to individuals at risk of homelessness[4]. The major external industries and sectors that influence the performance of the modular construction industry in Australia include mining, public infrastructure construction, private residential construction, agriculture, and institutional building construction.

[8] Latham, D (2024) The future is prefabricated: Prefabrication and modular construction Dane Latham. Latham. Available from https://bit.ly/3zieh5Z

[9] IBISWorld (2023) Industry Report: Prefabricated metal building manufacturing in Australia. Available from https://bit.ly/4glrxHz

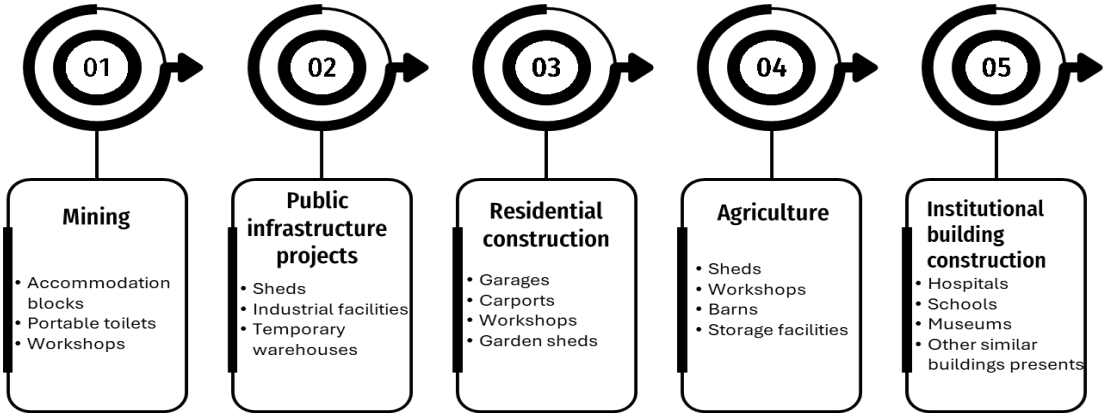

Figure 1. Major industries and sectors influencing modular construction and the relevant product examples

Reports[9] suggest a positive growth in demand from institutional building construction, public infrastructure construction, and mining sectors in 2023-24. However, a decline is expected in private residential construction and agriculture sectors.

PrefabAUS[4] estimates indicate that the Australian modular construction industry has the potential to yield annual benefits of $9 billion. This estimation is based on the assumption of a 20% cost saving and the nation achieving a 30% share of modular construction in the construction market by 2033. According to a recent report by IBISWorld[9], the prefabricated metal building manufacturing industry is projected to experience an annual revenue growth rate of 1.7% over the five years through 2028-29, reaching $3.0 billion.

When it comes to support for the Australian modular construction industry, two key factors stand out. The industry benefits from free trade agreements with China, Vietnam, and New Zealand. These agreements exempt prefabricated metal building products from the general tariff of 5.0%, making exports to these markets easier. Over the past five years, these trade deals have helped industry exporters expand their access to international customers. Additionally, manufacturers are protected by anti-dumping laws, ensuring fair competition and safeguarding against unfair trading practices. PrefabAUS is an industry association dedicated to promoting and supporting the use of prefabricated construction methods to enhance construction efficiency, sustainability, and affordability. The organization serves as a bridge between manufacturers and government agencies, advocating for the sector's interests and needs. Through collaboration with relevant bodies, PrefabAUS plays a crucial role in influencing policies, regulations, and standards affecting the modular building sector.

3.2 Drivers of adopting modular construction in the residential sector

The application of this construction methodology in Australia is driven by five major factors (Figure 2). Modular housing in Australia has been advocated as both an immediate response to accommodate those who are affected by natural disasters (short term), and a rapid method to deliver permanent residences, aiming to alleviate the nation’s housing shortage (long-term) and a solution to the limited supply of construction labour (medium-term)[4]. Recently, modular housing has been used as an efficient solution for flood relief in the Northern Rivers of NSW and central west towns such as Eugowra.

Disaster relief solution	Short term response to post disaster management
Solution to housing crises	Permanent family homes to address housing shortage
Limited construction labour	Compensating for ongoing skilled labour shortages with increased productivity rates
High construction wages	Streamlining labour processes and reducing the need for extensive on-site work
Increased interest and investment	Recent increased interest by public and private sectors in modular construction application and manufacturing

Figure 2. The main drivers for using modular construction in Australia

In Australia, limited construction skilled labour presents an opportunity and incentive to quickly scale up the prefabrication industry for success in the residential sector. Furthermore, Australia is known for paying some of the highest construction labour wages globally. Factors contributing to this include Australia's high cost of living, strong labour unions, stringent workplace health and safety regulations, and the nation's resource-rich economy, which drives up wages in industries like construction.

The majority of Australian builders are small businesses with one or two people, relying heavily on subcontracted and agency labour for various stages of building projects. A recent report published by IBISWorld[10] indicated that the COVID-19 pandemic severely disrupted supply chains for building materials, fuel, capital equipment and skilled labour; delaying building progress and escalating input prices and wage rates in Australia. The use of modular construction can compensate for the skilled labour shortage as it provides higher rates of construction productivity. Since unmet housing demand and the relative scarcity and cost of construction labour are the major predictors of where modular construction can gain traction, a report by McKinsey & Company[3] showed where these two factors intersect as depicted in Figure 3. This report highlights the potential growth in markets such as Australia, the UK, Singapore, and the US regional.

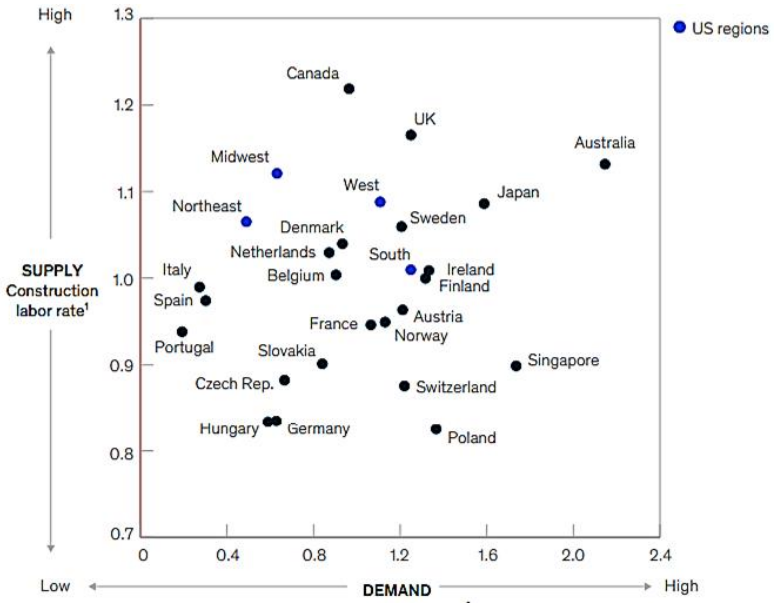

Figure 3. Near-term demand for new housing against construction labour supply
Source: Bertram et al. (2019)[3]

[10] IBISWorld (2023) Industry Report: House construction in Australia. Available from https://bit.ly/3XInu0K

There has been a notable rise in interest and investment in modular construction recently. This increase is largely attributed to the Australian government's commitment to procuring prefabricated construction structures, as detailed in 3.1.

3.3 Barriers to adopting modular construction in the residential sector

Barriers to adopting this methodology in Australia come in different forms and at various levels of impact. There is limited knowledge of modular construction applicability nationwide. The industry model in Australia is primarily focused on basic and remote housing, with prefabrication largely limited to the basic definition of offsite production. However, the industry has yet to fully embrace new processes and models on a larger scale. In many cases, Australian prefabrication simply transfers traditional construction methods to a factory setting[4]. This is of particular importance, as the scale is needed to justify investment across off-site construction manufacturing and application. Figure 4 provides a summary of the major barriers to using modular construction in Australia.

Limited knowledge of applicability	Industry yet to adopt the new processes and models at scale
Capital costs	Significant initial investments for acquiring production facilities, specialised equipment, and marketing
Insufficient buyback fund	Low government budget allocated to enable natural disaster affected communities to purchase modular
Inefficient rollouts	Inefficient process due to excessive delays, ineffective site preparation and poor communication with the

Figure 4. The main barriers to using modular construction in Australia

Establishing modular manufacturing incurs significant capital costs. The initial investment is required to set up the infrastructure, equipment, and processes necessary for efficient and effective production of modular components. As outlined before, the pandemic-related disruptions have added to the complexity and contributed to higher setup costs. This together with the uncertainties about the return on investment (ROI) in the industry has made setting up modular construction facilities more challenging and costly, posing a major hurdle for the industry in Australia.

The complexity of using modular construction as a disaster relief solution is intertwined with government initiatives. In a recent article published in the Gurdian[12], three major barriers to the application of modular construction as a disaster relief solution were reported to be the lack of community consultation, small funding pools for buyback initiatives, and inefficient rollouts. According to the reports[11], the buyback initiatives in Australia may not offer property buybacks at pre-disaster values for all disaster-affected communities. Having access to this fund would have been beneficial for these communities to raise their homes, especially those considering modular construction as a quick accommodation solution. The issue with inefficient rollouts in natural disaster-affected areas is linked to the delays in providing modular temporary housing solutions, ineffective construction site preparation and poor communications with the stakeholders[12].

[11] Rose, T (2023) Buyback offers to reach 1,100 northern NSW homeowners, 500 fewer than hoped by agency boss. The Gurdian. Available from https://bit.ly/3Zt5jxw

[12] Rose, T (2022) Emergency housing rollout across flood-hit NSW north coast a 'dog's breakfast', critics say. The Gurdian. Available from https://bit.ly/4eqG3Me

3.4 Environmental benefits of using PwRC in modular construction

As visualised in Figure 5, there are five major environmental benefits with respect to using PwRC in modular construction. The first environmental benefit of this approach is carbon emission savings. Carbon savings primarily result from the reduced consumption of natural resources in the building and construction sector due to the utilisation of PwRC. Carbon emission saving can be estimated using a range of available metrics including global warming potential (measured in t CO_2 eq)[13]. The findings of an empirical research study[14] indicate that modular construction reduces embodied energy by 56% and 26% in small and large structures, respectively. Technically, this can offset the additional carbon emissions arising from waste recycling, thus improving the environmental performance of PwRC.

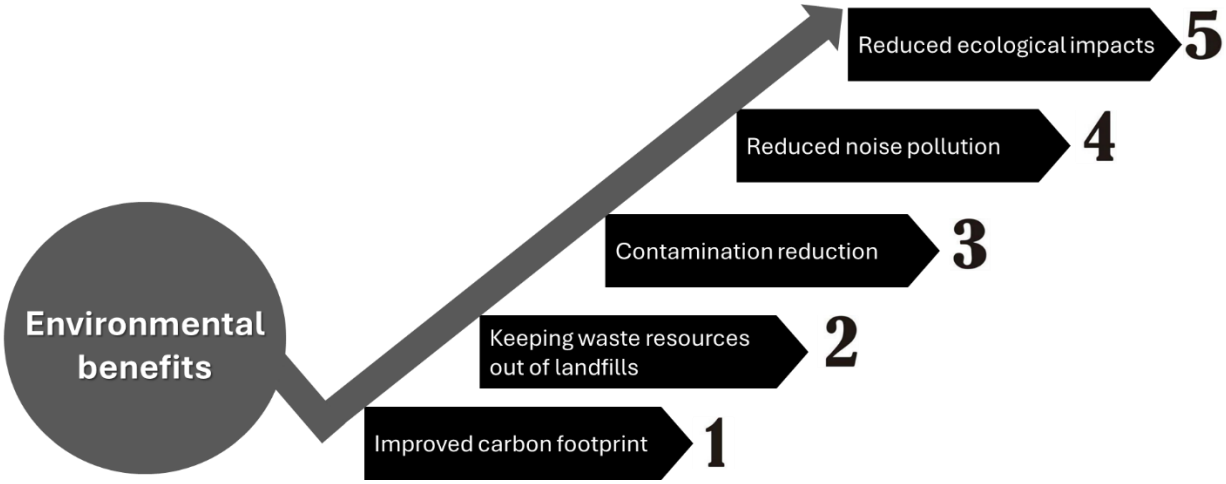

Figure 5. The major environmental benefits of using PwRC in modular construction

The use of secondary materials in modular construction occurs in two different forms: recycled materials and nonrecycled materials. A research study in Australia[13] showed that reusing waste non-recycled resources has a superior carbon footprint than recycled materials. This is because some PwRC are invariably wasted or contaminated in the process, and the recycling process requires energy consumption. In some cases, construction and demolition waste from a site can be reused in the new construction, reducing the necessity to transport these materials to and from recycling facilities. A study conducted in Australia[15] indicated that reusing demolition waste in the new construction on the same site has resulted in 1,000 fewer truck movements, 9,000 L of diesel saved, and therefore, 663 t of CO_2 were avoided. The study found that the carbon emission reductions were achieved in three key areas: onsite, through the replacement of raw materials with recovered demolition products; offsite, through recycling; and during transport, through reduced truck movements.

The second benefit is related to reduced waste disposal from demolition activities. Modular designs enable not only offsite construction but offsite demolition as well. A University of Melbourne's Centre for Advanced Manufacturing of Prefabricated Housing report[16] suggests that all components of modular construction can be reused, thus eliminating the waste that would typically end up in landfills.

The third advantage focuses on minimizing the risk of waste resource contamination at the end of their service life. Modular constructions are usually designed for easy disassembly, reducing the

[13] Minunno, R., O'Grady, T., Morrison, G. M. and Gruner, R. L. (2020) Exploring environmental benefits of reuse and recycle practices: A circular economy case study of a modular building, *Resources, Conservation and Recycling*, 160, 104855.

[14] Hammad, A.W.A.; Akbarnezhad, A.; Wu, P.; Wang, X.; Haddad, A (2019) Building information modelling-based framework to contrast conventional and modular construction methods through selected sustainability factors. *Journal of Cleaner Production*. 228, 1264–1281.

[15] Shooshtarian S, Maqsood T, Wong PSP, Caldera S, Ryley T, Zaman A and Caceres Ruiz AAM (2024) 'Circular economy in action: The application of products with recycled content in construction projects: A case study approach'. *Smart and Sustainable Built Environment*. 13(2): 370-394.

[16] Mendi, P (2022) 'Circular economy, modular construction and recycled materials'. Centre for Advanced Manufacturing of Prefabricated Housing. Presented at the Institution of Civil Engineers Australasia. Available from https://bit.ly/4d99PEc

contamination of separated waste resources and extending their lifespan for second or subsequent lifecycles. Additionally, modular construction processes reduce the impact of potentially environmentally hazardous waste materials, which are more challenging to manage compared to non-hazardous construction and demolition waste materials.

The fourth advantage of using PwRC in modular construction is the reduction of noise pollution. In the environmentally controlled setting of an off-site factory, the process of repurposing and applying resultant PwRC in prefabricated building elements can be completed with minimal environmental noise. This is in contrast to on-site construction, where the use of materials and construction methods can lead to significant noise disturbances for nearby residents and businesses. By conducting these processes in a controlled factory environment, noise pollution can be greatly reduced, contributing to the sustainable application of these PwRC.

The last environmental advantage of this application is the reduced impacts on the ecology. Since the majority of application of PwRC in a modular approach takes place off-site, it significantly diminishes the ecological impact including reduced soil erosion and less harm to the local ecosystem.

3.5 Economic benefits of using PwRC in modular construction

The use of PwRC in modular construction can provide multiple economic benefits (Figure 6). The first benefit is the decreased requirement for rework caused by building defects. Off-site construction allows for the highest quality of construction, leading to enhanced implementation of PwRC with minimal waste from defects during both construction and operation. This results in cost savings for constructors and building owners by avoiding the costs associated with rework. Moreover, when constructed to withstand earthquakes and high wind loads, they often outperform conventional structures designed to resist these forces[2]. This advantage can reduce externally induced defects in prefabricated components that incorporate PwRC.

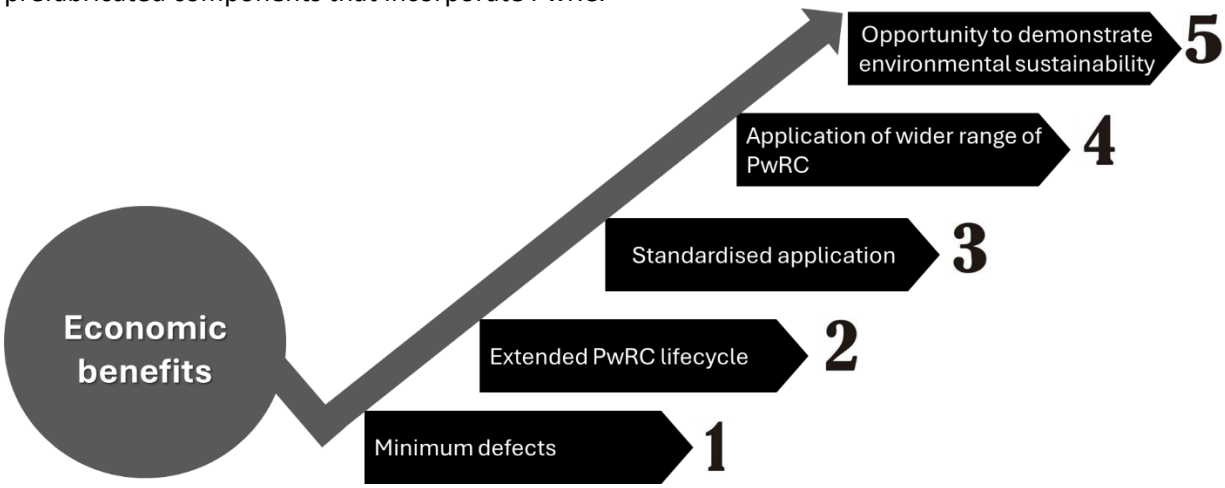

Figure 6. The major economic benefits of using PwRC in modular construction

The second benefit involves extending the PwRC lifecycle. Although an increasing portion of modular construction focuses on permanent structures (similar to conventional buildings), many businesses continue to utilise modular buildings for temporary purposes. Relocatable buildings are brought to sites for rapid expansion or as temporary facilities for students, patients, or employees during renovations or emergencies. Once the additional space is no longer required, the modular building is taken off-site and repurposed for future use. This indicates that PwRC can continue to function as a construction material, reducing the need for demolition and greatly enhancing its circularity.

The third benefit is in connection with a more standardised (industrialised) approach to using PwRC reduces the complexity of utilising these waste-based resources. This streamlined approach enhances their application, leading to significant cost savings. Furthermore, as the prefabricated modules are

repeatedly produced for clients, supplies can be ordered and stored onsite. This enables any PwRC leftover resources from one project to be used in subsequent modules, enhancing their utilization efficiency, especially during supply shortages. Moreover, with the increasing interest in prefabricated buildings, the use of PwRC in this industry can tap into a new and sustainable market. This, in turn, fosters an economy of scale that ultimately enhances the economic competitiveness of PwRC.

The fourth benefit focuses on the application of a wider range of PwRC in an industrialised environment. Constructors can explore innovative ways to incorporate various PwRC that may not be feasible in onsite construction due to constraints such as time and space limitations or safety requirements. The increased demand for a wider range of PwRC can attract investment in advanced repurposing technologies and the development of new supply chains. This, in turn, can lead to a reduction in the production cost of these resources.

The last benefit involves capacity building within the modular construction industry and organisations to enhance their environmental sustainability and showcase it effectively. In many countries, including Australia, environmental sustainability initiatives such as Zero Waste movements urge the government and the industry to take a more circular approach. This is now clearly reflected in the decision-making processes of organisations involved in the building and construction sector. In such scenarios, these organisations are incentivised to utilise PwRC to showcase their sustainable practices in business operations[17] and to be recognised by various environmental sustainability rating schemes[18]. This will increase the likelihood of securing additional construction contracts that prioritise environmental sustainability. In a recent study conducted in Australia[15], the research participants indicated that the need for organisations to ensure competitive advantage and future-proofing was identified as the second main motivation for using PwRC in construction projects.

[17] Shooshtarian S, Maqsood T, Wong PSP and Bettini L (2022) 'Application of sustainable procurement policy to improve the circularity of construction and demolition waste resources in Australia'. *Materials Circular Economy*. 4(27): 1-22.

[18] Shooshtarian S, Maqsood T, Wong PSP, Zaman A and Ryley T (2024) 'Utilisation of certification schemes for recycled products in the Australian building and construction sector'. *Business Strategy and the Environment*. 2024(33): 1759-1777.

4 AN OVERVIEW OF ATCO S&L

4.1 Background

ATCO Structures and Logistics (ATCO S&L) is a private company that earns most of its revenue from the commercial and industrial building construction sector. It is engaged in the construction, sale, and hire of transportable buildings. In 2024, this manufacturing organisation is projected to hold 6.5% of the market share for prefabricated metal building manufacturing, ranking it as the second-largest manufacturer in Australia in this category[9]. The company operates sales offices and manufacturing facilities throughout Australia with a particular focus on Queensland, Victoria and Western Australia through the divisions outlined in Table 3.

Table 3. ATCO S&L's divisions of operation

Division	Description
Modular buildings for hire & sale	Accommodation buildings, daycares and schools, kitchen and diners, commercial offices, parks cabins, classrooms, recreation and gymnasiums, site offices and demountable, toilets and ablutions, and trailer mounted units
Atco villages	Furnished accommodation for workers in the construction, mining, education, oil and gas and other commercial industries
Manufacturing capability	A wide range of modular products such as blast-resistant modular buildings, customised modular buildings, education facilities, residential, commercial, switch room and control rooms, office accommodation, and accommodation villages and camps
Project construction services -	design and engineering, project life cycle and control, master planning, civil works, project management, contracting, pre-engineered buildings, sport and recreational facilities, water and wastewater management, power generation, building approvals and certification, service and maintenance, contracting, and logistics management (road and shipping)

The main ATCO S&L modular products include commercial offices, government facilities (e.g. emergency, health and custodial services), sporting facilities and educational facilities[19]. These products are (custom) designed, manufactured, transported and installed by ATCO S&L either temporarily or permanently (Figure 7).

Figure 7. Top left (office building), top right (educational building), bottom left (sporting facility), bottom right (correctional facility).
Source: ATCO Structures and Logistics (2024)[19]

[19] ATCO Structures and Logistics (2024) Off-site modular construction offers efficiencies over in-site. Available from https://bit.ly/3zoTAFn

4.2 Organisational environmental sustainability

ATCO S&L data shows that PwRCs are utilised in diverse building elements, including base steel, base, roof, wall, and window materials, as well as lifters. The proportion of recycled content varies, with roof, wall, and window materials containing 17.4%, base materials 25%, and lifters and base steel containing as high as 98% recycled content.

5 APPLICATION OF PWRC IN ATCO S&L

5.1 Descriptive findings: Participants profile

Six key stakeholders who influence the use of PwRC in modular construction products were interviewed between March and March 2024 (Table 4). The interviewees were experienced individuals with a significant track record of involvement in modular construction in Australia. Five of these interviewees were employed in different departments of ATCO S&L and were based in Queensland at the time of the interview.

The technical manager of the study organisation (C_1P_1) was a design engineer by background with extensive engagement in a wide range of MMC activities on a global scale. He also managed the compliance and engineering aspects of the organisation's modular products. The design manager of ATCO S&L (C_1P_1) had worked for the organisation for more than 10 years, with the overall responsibility of designing modular buildings. The operations manager (C_1P_3) had also extensive experience in the building and construction sector particularly in the MMC industry. The organisation branch manager (C_1P_4) had stayed with the ATCO S&L for 14 years, with a speciality in business development and sales and marketing. The Health, Safety, Environment and Quality (HSEQ) manager of the organisation (C_1P_5) had expertise in various fields and employment sectors. The last interviewee (C_1P_6) was the representative of an organisation that supplied recycled steel to ATCO S&L.

Table 4. Summary of participants' profiles in Case Study 1

Stakeholder type	Experience/expertise	Participant code
Technical Manager	25 years of experience in various sub-fields of MMC in Europe, North America, Africa and Australia. Management of engineering and compliance aspects of the organisation's modular products.	C_1P_1
Design Manager	More than 15 years of experience in the Australian MMC industry with responsibilities including detailing, designing and estimation	C_1P_2
Operations Manager	More than 25 years of working experience in the Australian MMC industry.	C_1P_3
Branch Manager	Extensive experience working in the study organisation's business development sales departments.	C_1P_4
National HSEQ* Manager	A manager with experience in different fields and employment sectors including work health and safety, construction markets and education and training.	C_1P_5
Supplier	Representative of supplying organisation (steel) with expertise in sustainability and extensive experience in the steel manufacturing industry.	C_1P_6

*HSEQ: Health, Safety, Environment and Quality

When asked about their history of involvement in C&D waste management in their current or previous roles, the participants reported varying levels of exposure to this field. C_1P_1 primary experience in this field relates to the design engineering of modular components to reduce waste generation. C_1P_4 indicated that ATCO S&L is involved in waste minimisation and reusing the waste, to limit the waste of their products. C_1P_5 reported that his exposure to the waste management industry was through various contracts he had with organisations both in the industry and outside of that. He also mentioned that he is involved in managing waste in ATCO S&L. C_1P_6 mentioned that their organisation is involved in the recycling of metals in Australia. The rest of the participants did not have any direct involvement

with waste management, as the modular construction industry does not typically generate too much C&D waste during manufacturing, transport, installation or operation.

5.2 C&D waste management and procurement of PwRC

This section outlines the organisation's involvement in C&D waste management and the integration of PwRC in modular building products. It begins by detailing the organisation's strategies for managing C&D waste resources, followed by an overview of their initiatives for reusing modular products and procuring PwRC for new construction and retrofitting projects. Additionally, the contributions of each participant involved in these activities are highlighted where applicable. While some participants were directly involved in the procurement process, others were not, resulting in varying levels of understanding of the organization's procurement procedures among different participants.

Typically, the off-cuts and waste materials generated during the manufacturing and installation of modular buildings are disposed of in recycling bins. These waste resources are managed through three potential pathways: 1. Collection by third-party waste operators, 2. Reuse in the production of new building products or applications in the retrofitting projects, or 3. Disposal in landfills. To minimise waste generation, the organisation set a criterion for material procurement focusing on the 'packaging materials' issues. *C_1P_1* reported that in some cases, the organisation negotiates with the supplier to reduce packaging waste materials. However, in most cases, the off-cuts and other waste materials are dumped into recycling bins, where, as outlined above, they might be reused in ACTO S&L products. An example of this reuse is for framed decks,

> *'Framed decks are typically lined with a structural ply lining on top...we may find that that structural ply is kind of weathered. So we will take that part off the deck…But we will reuse the deck frame, and reline it so that we don't have to continually go and get more steel framing built for our jobs. And we can continually reuse that'* [C_1P_4]

Other materials that are reused in this organisation are presented below.

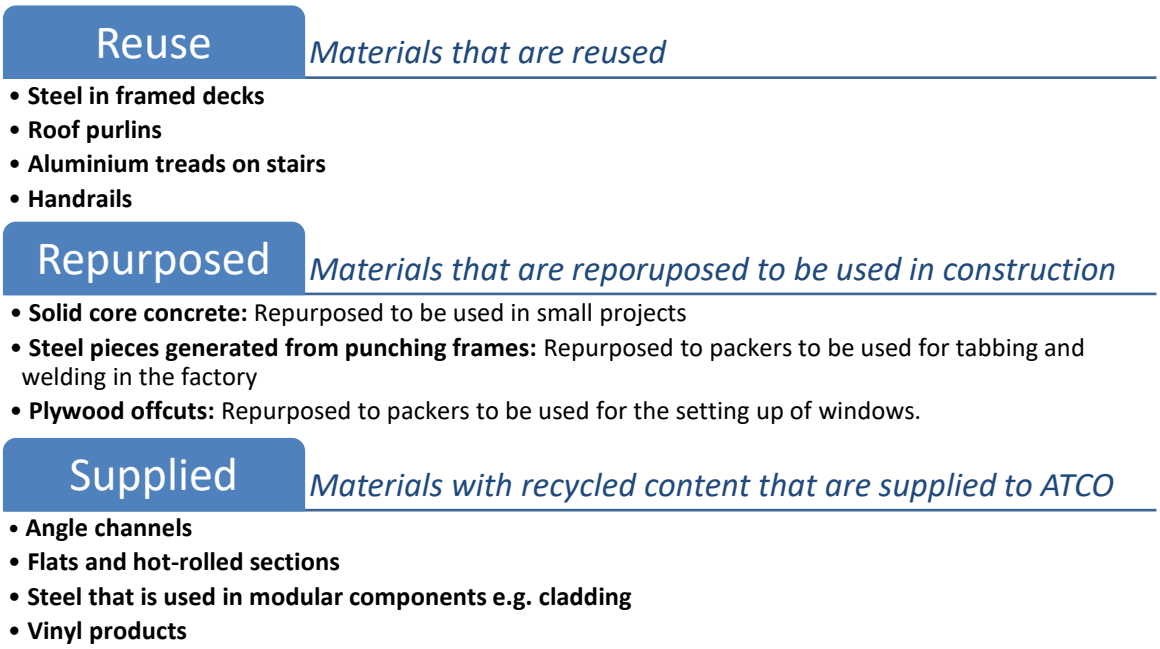

Figure 8. Examples of reusing construction materials in Case Study 1**.**

In this section, the organisational procurement model is reviewed and some of the procurement criteria being used are presented. Overall, despite having slightly different procurement criteria, the PwRC procurement model is not different from other alternatives (*C_1P_5*), and their utilisation is to a limited extent as indicated by *C_1P_3,*

> *'The process of procuring waste materials, it would be no different to procuring any material'* [C_1P_5].

> *'We don't tend to use a lot of recycled products if I'm being honest. When we do it, it would usually be in line with the tender requirements…occasionally we use recycled decking products and decking boards. That's about it.'* [C_1P_3].

According to the interviews, there are several factors influencing the procurement of PwRC in ATCO S&L products. These factors are listed in Sections 5.5-5.7. It also appears that there are currently no specific criteria established for the procurement of PwRC. However, the most commonly cited criteria for PwRC procurement include cost, availability, associated risk, and suitability. *C_1P_2* reported that

> *'It's still more like in a pipeline to look at those recycled materials, but again it all comes down to what's the cost involved in those materials, the availability of those materials and if there's any risk'* [C_1P_2].

In ATCO S&L, generally, the design team specifies the construction materials based on the individual designs, which will be passed on to the manufacturing sector to procure. For the procurement of PwRC, these are suppliers that reach out to the organisation to sell their products. They share their products' specifications with the organisation (i.e. compliance team) to review them for fit for purposes point of view of the organisation.

> *'There are some products that now we've been introducing, that we're investigating to use as we can see a lot a few of, a couple of sales reps from different recycling companies, they're start coming into the business and introduce the product'* [C_1P_2].

Most products are supplied through shorter supply chains with whom ATCO S&L established business arrangements. For instance, *C_1P_6,* the supplying organisation representative, indicated that they supply steel construction products/materials, some with a high level of recycled content to ATCO S&L. These materials include smaller angles channels, flats and other hot rolled sections (Table 4). The participant also commented on the upstream material supply chain. They primarily purchase metal waste materials from demolition companies who in turn extract them from building demolition projects. Additionally, they source them from the manufacturing businesses, their manufacturing unit, and the general public.

> *'So anyone can come in with a trailer or a boot full of scrap metal, you know, not just steel, but copper, aluminium and other metals, and they would be purchased over the counter'* [C_1P_6].

There are four reasons why the organisation tends to choose a shorter supply chain when procuring materials, these include (1) the trust established between parties to avoid falling into the greenwashing trap, (2) avoiding product variability (3) more control over meeting product quality requirements, and (4) lower prices.

> *'It was always to shorten the supply chain because you can reduce obviously variability, but you can also get closer to what you want rather than what you're given…and then usually that ends up reflecting in a lower price'* [C_1P_1]

In some cases, the procurement is carried out by other suppliers for specific products e.g. timber products. For example, *C_1P_1* indicated that timber products are sometimes sourced from outside of the shorter supply chain arrangement:

> *'Sometimes substitution comes by via an established supplier, and sometimes they come from different sources and so, for example, we have a supplier who supplies timber and timber products and they source them from all over the world'* [C_1P_1].

5.3 Sustainability benefits

In this section of the report, the sustainability advantages of incorporating PwRC in modular construction, as perceived by the research participants, are thoroughly examined. The insights from the interviews provide a valuable complement to the literature review findings discussed in Sections 3.43 and 3.5. As illustrated in Figure 9, the participants identified ten key benefits of such an application that enhance social, environmental, and economic sustainability outcomes in modular construction.

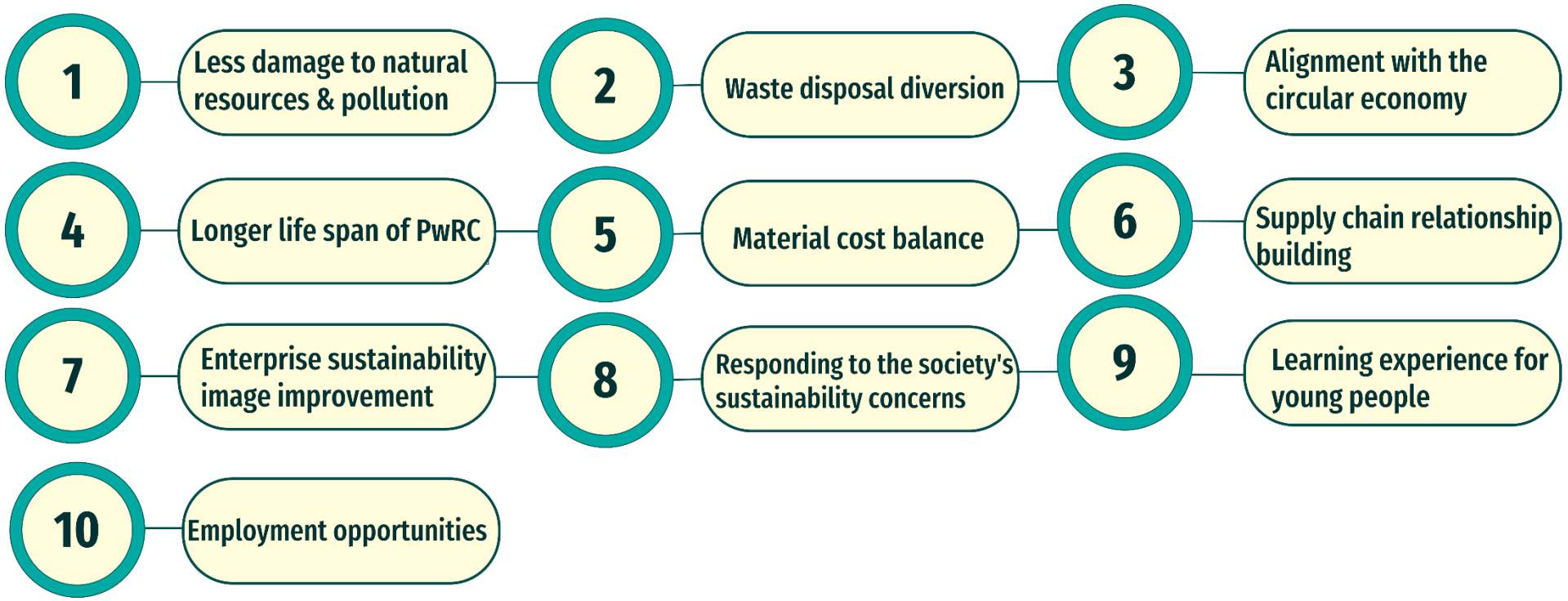

Figure 9. The major benefits of using PwRC in modular construction

1) Less damage to natural resources & pollution

In participants' views, the use of PwRC in modular construction can enhance the environmental sustainability of the building and construction sector. The reduced need for extracting virgin materials contributes to environmental protection and pollution reduction.

> *'Recycled products are better than, say, chopping down trees and creating decking boards and Poly ply and whatever else'.* [C_1P_3]

> *'It's reducing even the amount of raw product we're taking from the planet, raw deforestation for mines'* [C_1P_5]

2) Waste disposal diversion

The application of PwRC can generate demand for waste resources, which in turn reduces the volume of waste sent to landfills. Waste disposal diversion results in improved economic and environmental sustainability in the sector.

> *'Where we're using recycled products is a great thing because it's reducing landfill, it's reducing microplastics in the ocean'* [C_1P_5]

> *'Diversion of waste away from a waste stream back into a recycling stream'* [C_1P_6]

3) Alignment with the circular economy concept

Within the circular economy concept, the use of PwRC is emphasised as a key strategy to maintain the value of materials in the economy for as long as possible. According to C_1P_1, utilising locally sourced PwRC can further enhance the sector's circularity by reducing the need for transportation and energy consumption.

> *'If the market makes that circle of the circular economy as small as possible, rather than sending, your waste all the way to either China or India or somewhere in Europe or North America to then, be recycled there and probably reused there'.* [C_1P_1]

> *'That's* [using recycled products] *the idea of how you can do more with less. The idea of generating less waste is important, but use less to, use less energy, generate fewer emissions, increased circularity, increasing material efficiency'* [C_1P_6]

4) Longer life span of PwRC

One participant indicated that some PwRCs have better durability compared to products created from virgin materials. According to C_1P_4, This in the long run can provide an economic advantage for the manufacturer of modular products.

> *'A lot of these recycled products have a longer life span than the other ones. So whilst they may be a higher initial investment, they certainly provide better economical advantages over the long term'* [C_1P_4]

5) Material cost balance

As the consumption of natural resources continues to rise across various industries and for a range of products, their prices will likely increase. Additionally, in certain applications, the use of PwRC may not be technically feasible, leading to intense competition for virgin materials. Therefore, in the future, incorporating PwRC in modular construction could play a significant role in enhancing the economic sustainability of the building and construction sector.

> *'If we're not using recycled products, the cost of a raw product style material will start to outweigh the cost of recycled material because there's less and less of it'* [C_1P_5]

'All of a sudden you're competing for those raw minerals because they're going into producing solar farms and wind farms.. which means there's less for general steel production, etc.' [C_1P_5]

6) Supply chain relationship building

Given the reasons mentioned above, the use of sustainable materials is expected to increase across various industries. Therefore, it is prudent to begin adopting PwRC, which will, in turn, help establish an effective supply chain for these products. Working with an established supply chain will enhance the economic sustainability of the modular manufacturing industry. C_1P_5 indicated that the earlier development of such supply chains is a key to success in this space.

'So I think from an economic point of view, the earlier you move into that, the earlier you secure supply chain, the earlier you build those relationships, it's going to be better for you when that cost economy starts to change' [C_1P_5]

7) Enterprise sustainability image improvement

The use of PwRC can enhance the enterprise's social image of businesses operating within the building and construction sector. In the current climate, where the sector faces severe criticism for unsustainable practices, the application of these products not only supports social sustainability but, according to C_1P_4, can also offer economic advantages by partnering with organisations that either fund sustainability-focused projects or seek to market themselves as sustainable businesses.

'I guess that it comes down to ATCO's place in the world and ATCO being seen to be using recycled materials and being seen to be green and reducing your carbon footprint'. [C_1P_3]

*'but one of our competitors was openly promoting themselves and demonstrating that they were using recycled steel … And then you've got a big, $500 million project that's being funded by the federal government, managed by a tier one company, which tier one company is going to go with ATCO over the competitor that's marketing themselves and has that positive social influence?'* [C_1P_5]

8) Responding to the society's sustainability concerns

Societies worldwide, especially in developed nations, have gained greater awareness of environmental sustainability. As a result, there has been a significant increase in demand for sustainable practices and policies in different industries and sectors over the recent years. The use of PwRC can contribute to the overall sustainability of the sector, effectively addressing this growing demand.

'We can see socially that society is pushing more and more and more for sustainability. They want green energy; they want less products and pollution. They want the electrification of the grid. They want to know that the people that they're getting things from are having the least amount of impact on the Earth for their future generations and for their own health. So, I think from a primary social area, it really comes down to how you market yourself and remain at the forefront of people's minds that are potentially buying your products' [C_1P_5]

9) A learning experience for young people

According to two participants (C_1P_1 and C_1P_2), using PwRC in modular products, especially those used in educational settings, can offer valuable learning opportunities for young people. This exposure allows them to understand the application of these products in buildings and similar modular structures, fostering a mindset aligned with sustainability principles. Consequently, this can further enhance the social sustainability of the sector.

'daughter's school, they were having modular buildings installed and like everything else on a school site, gets turned into a learning experience for the children…and the story, where you're able to tell the story of a, particularly a modular constructed building, probably as a narrative' [C_1P_1]

the education sector across Australia is the driving force behind introducing new recycled materials. It's all about that, helping the environment and things like that' [C_1P_2]

10) Employment opportunities

The process of converting waste materials into products often involves several steps that are labour-intensive, creating employment opportunities compared to waste landfilling. Therefore, it can be concluded that utilising PwRC in modular construction offers significant benefits for social sustainability through triggering waste recovery activities that employment associated with them.

'It provides an economic return to those who return it to us as recyclers, the demolition companies, the manufacturers or, you know,…there's a social impact around that from an employment point of view' [C_1P_6]

5.4 Challenges of using PwRC in modular construction

The number of challenges identified as hindering the application of PwRC in the modular construction sector far exceeded our expectations. After consolidating some challenge categories, 16 categories emerged. These categories include a broad range of issues, including supply chain, cost, organisational limitations and technical complexities.Figure 10 illustrates these ten categories. The most commonly mentioned challenge category among these is 'cost complexities' followed by the 'industry conservative approach' and 'availability of PwRC'.

The following sections provide insights into the industry perceptions regarding these challenge categories; they are presented in no specific order. The challenges highlighted in this section offer a foundation for advancing the modular construction industry, particularly in enhancing the incorporation of PwRC in modular products.

Figure 10. The main challenges of using PwRC in modular construction

1) Project characteristics

The quality and quantity of PwRC utilisation in construction projects depend on various factors related to the project's nature, including both physical and non-physical aspects. These factors can hinder or complicate the use of PwRC in construction projects. As outlined by C_1P_4, these factors can include the building's age, the project's size, and the allocated budget.

> *'So we have buildings that are two months old and we have buildings that are 20 years old. And obviously, the specification between those two buildings varies a lot'.* [C_1P_4]

> *'But we can't really, on bigger jobs, it's harder for us to use those* [PwRC] *because our clients will go, "Well, hold on a second, this is a three-and-a-half million dollar job, why have I got second-hand materials here? What's this doing here? What's that doing here?'* [C_1P_4]

> *'Whether they've got a tight budget or a loose budget, whatever that may be…whether their project can allow for it that will determine whether they can take it or not'* [C_1P_4]

2) Cost complexities

The issue of cost complexities was cited by several research participants. This issue has three dimensions and can be divided into three subcategories based on the interviewees' responses: 1) The higher cost of PwRC compared to conventional materials, 2) Market interventions by competitors against PwRC supply, and 3) The client's willingness to pay extra for PwRC.

> *'In order to be marketable it would then have to have all of that testing, and when you amortise all of that testing into a product, becomes more expensive, particularly when you're trying to introduce it into a new market'* [C_1P_1]

> *'The exciting and the funny side of this is that you know, everyone's supposed to be recycled should be cheaper. But it's vice versa, right? When it comes to recycling the cost of the materials it's almost double the cost of the original, it's not that cheap* [C_1P_2]

> *'Generally, it's, it tends to be those recycled products are generally more expensive than standard, say timber products, particularly with decking boards'* [C_1P_3]

> *'If sustainability is number 1, then yeah, we're looking great. However, if the price is number 1, then those options can look quite expensive in the short term'* [C_1P_4]

> *'There is an element of cost competitiveness and I think that relates to a lot more to new product in the market versus established players, particularly when there might possibly be a premium being paid because of the lack of competition, which when competition comes in business…I'll say that business readjusts itself to suit the market, to maybe make it harder for a new entry to come into that market as well'* [C_1P_1]

> *'So there's the initial upfront capital cost interrogation of product for product comparison. Then there's the life of asset cost incorporating maintenance and replacement over a 15 or 20 year product life cycle'* [C_1P_5]

> *'Five, six, seven years ago, there used to be a push for air conditioners to have a certain star rating, for example, for their sustainability. Now, we would have to charge them to put new air conditioners into buildings so that they have that star rating and as soon as they saw the price of that, the answer was always, well, no, don't worry about it'* [C_1P_4]

3) Industry conservative approach

The building and construction sector is often viewed as resistant to innovation and change, with a strong aversion to the risks that come with any change. The industry's supply chain processes have been evolved over decades, and any request for change is seen as disruptive, leading to various complications. This resistance is especially evident among senior managers, who tend to rely on

familiar supply chains and products. C_1P_1 described conservatism as a sign of ignorance. Below are some comments from participants on this issue:

> *'The construction industry, by its nature, is very conservative. But, like I said, a lot of things that are based on, "It worked last time. I will do it again"… But I think it's a lack of imagination, is probably another way of looking at it and using a conservative, conservatism in the way of ignorance'* [C_1P_1]

> *'But when it comes to the modular industry, I would say 90% of the buildings, that use in the modular industry are they all using James Hardie products, for instance, or Colour, or Colourbond metal cladding'* [C_1P_2]

> *'Senior business managers in the larger modular firms, have spent most of their career in those businesses, so they're so comfortable and familiar with what they've done and their supply chain… Habitual mentality of, "We've always used this product. We're comfortable with this product. We know this product. We know this supplier'*[C_1P_5]

4) Greenwashing and product misrepresentation

This category refers to a well-established concept in the recycling practice and research. It is the practice of misleading end users by falsely claiming or exaggerating the environmental benefits or recycled content of a product. One participant (C_1P_1) suggested that greenwashed products could pose a challenge to the seamless acceptance of PwRC in the sector.

> *'There are some that have been green-washed and placed into the market as well…*[they] *are sold as green that essentially aren't, and they're still charging a premium or the selling a product that is not necessarily fit for purpose in terms of its longevity or application in our particular builds'* [C_1P_1]

> *'They all currently have drawbacks in either their credentials as being completely recycled material. Having recently done some testing on some materials where they say, "Oh, it was made from this and this", and so due diligence and only a few hundred dollars later, I can get a test done and have it put to them that it's actually not what you say it is. So you actually misrepresenting your product'* [C_1P_1]

5) Limited availability of PwRC and an immature supply chain

The limited availability of PwRC was a concern raised by three participants, who highlighted its significance given the volume and industrialised nature of modular construction. They pointed out that in modular construction the components must be readily available and supplied to manufacturing sites on time to prevent any disruption to the sequential production processes. One participant (C_1P_1) highlighted that the availability of some PwRC is constrained by the comparatively small and immature supply chain operating in Australia, which serves a market of 25 million people. Below are some responses from the participants:

> *'An Australian supply chain that is only supplying a population of 25, 26 million people. So there's certain products that I know that are available elsewhere that are not available in Australia and there's barriers to entry for that as well … Some of the fire-rated products, some of the fire-rated board materials and stuff like that, readily available in the UK and Europe and* […] *in North America'* [C_1P_1]

> *'But again it's* [PwRC application] *all come down to what's the cost involved into those materials and the availability of those materials and if there's any risk'* [C_1P_2]

> *'Procurement and availability is a big one generally, we have tight timeframes when we manufacture, generally. We have production programming; we generally have tight production programmes. I guess material availability would be a big one'* [C_1P_3]

'Because, if you're already established in the market in terms of like BlueScope selling the coil and selling the purlin sections and everybody is used to that, there's no motivation for a disruptor in the market, just because the market is so small' [C_1P_1]

'There's not the ability for them [ATCO] *to say, "I've got two products, and I can choose a recycled one, or high recycled content or a low recycled content one", in terms of the Australian landscape for steel products, what you get is what you get'* [C_1P_6]

6) Lack of organisational or regulatory targets for using PwRC

Organisational or regulatory targets can significantly encourage the use of PwRC by providing clear goals and incentives for organisations. These targets provide a structured approach to incorporating PwRC, aligning organisational practices with broader environmental goals. The lack of established targets for using these resources can reduce the motivation, accountability, and innovation needed to effectively incorporate them into construction projects.

The findings from the interviews indicate that, at present, there are no targets for using PwRC in modular construction within the study organisation, nor is there any policy in place to encourage their use. Some relevant responses are provided below:

But at this point, we're not yet into that area. We're not yet sure, we're still in like the reviewing process stage of those products and like assessment, but it hasn't been making up a firm call on those alternative reusable materials. [C_1P_2]

We don't tend to use a lot of recycled products if I'm being honest. Then, when we do, it would usually be in line with the tender requirements [C_1P_3]

'We might be procuring something that has raw waste blended into it. But that's the same thing, we're not necessarily looking or setting expectations to our suppliers that, "Hey, we're going to procure this, and we want it to have at least 5% blended waste product in it because it's a society, a sustainability initiative". We haven't got to that point' [C_1P_5]

'I guess the government is all about being green as well…[but] *they don't currently have any policy around using recycled material, they don't tend to'* [C_1P_3]

'In regional areas or lower tier builders who don't have those things [obligatory incorporation of recycled content] *commercially put into their deals, you know, they don't need to get recycled product. It's not mandated for them to do that. Therefore, they are often the smaller builders who will take the cheaper option'* [C_1P_4]

7) Lack of precedent in PwRC application

One participant observed that the modular construction industry tends to be cautious about using products that lack market testing. Demonstrated performance from previous use can build market confidence and foster wider adoption of these products. C_1P_2 noted that while laboratory tests are a useful way to understand the nature of a product, they do not equate to assessing its actual utilisation and performance in modular components.

'It's more like a salesperson walking in, "Hey, we've got this recycle substrate board", right? It hasn't been tested on the market and it's more like they want us to have a look at that. So we're kind of looking to other what other competitors are doing at the moment where the other competitors are' [C_1P_2]

'Like I said, it's been tested in the laboratory, but when it comes to if it's in construction itself, it hasn't been tested in that area' [C_1P_2]

'Whereas in the industry they introduce like different recycled materials. But then when we use those recycled materials in apartments, they can catch fire and it's the problem is that there are a lot of other companies that produce equivalent to those materials' [C_1P_3]

8) Health and safety issues

The use of PwRC presents health and safety complications. Physical and chemical changes during recycling processes can cause the industry to be cautious about using recycled materials due to potential health and safety issues. C_1P_2 highlighted that it is not advisable to use PwRC which lacks accompanying safety data.

'One of the issues that come from potentially looking at recyclable materials can come from, how good the data is around the safety of that product, and therefore the understanding and interpretation of potential controls or exposure for the workers. But do we know if it's safe to use when we're cutting it and sending it? Heating it? Glueing it, etc.? Washing it? That probably provides a little bit of fear response, which prevents them from looking at that space at the moment' [C_1P_5]

9) Lack of certification for recycled products

As indicated in the previous category, the unknown nature of recycled materials can hinder their widespread application in modular construction. The lack of a formal assessment of PwRC performance, safety and quality can lead to uncertainty and reluctance in their adoption, as stakeholders may have insufficient information to evaluate their suitability and reliability for construction projects.

'Only a few hundred dollars later, I can get a test done and have it put to them [material supplier] that it's actually not what you say it is' [C_1P_1]

'The problem is that there are a lot of other companies that produce equivalent to those materials but haven't been tested or going through the process of assessing the nature of those products. And that's why we have the issue in the industry of materials that get caught in a fire and there was no proper certification' [C_1P_2]

'…but what about the safety data sheet? What about the health?" and the person that was providing it to us didn't have the greatest knowledge yet… So, because those things weren't answerable, we had to say, well, we can't use the product, but to me it looked like a great product' [C_1P_5]

10) PwRC longevity and performance

In the building and construction sector, the longevity and performance of materials are crucial for the successful delivery of projects. Uncertainty regarding the longevity and performance of PwRC has been cited as a major factor limiting their use in modular construction. Several participants emphasised the importance of addressing this concern when considering the procurement of PwRC.

'But the cost and availability of this product and performance of the product is, is one of the key areas that we can consider at this point' [C_1P_2]

'I think businesses would be open to using recycled materials as long as there was longevity in the material' [C_1P_3]

'So there's a bit of a market expectation on us as well to make sure that what we're providing is of a higher or highest quality' [C_1P_4]

11) Lack of experience dealing with the PwRC supply chain

As previously noted, the study organisation currently has limited capacity to incorporate PwRC into its modular products. One participant reported that the organisation does not have a procurement strategy specific to PwRC. Consequently, their ability to effectively engage with the PwRC supply chain

is also constrained. Two participants observed that this limitation could affect their procurement processes, even if the organisation is willing to enhance its sustainability impacts through the use of PwRC.

> *'So that's 100% something that I think ATCO is aware that it's got to get, but I don't know if ATCO has enough experience yet to be able to understand how to have those conversations with suppliers to then target that and look at that* [C_1P_5]

> *'The process of procuring waste materials would be no different to procuring any material. We would be, you know, trying to find it, we would be trying to understand it'* [C_1P_5]

> *'I think, it's really the challenges that they face around increasing recycled content is around engaging those suppliers and what they're doing to drive, you know, drive change in their manufacturing route and yeah, so for us, it's something we've solved, but for those other manufacturers that I spoke about they're, they're each on a journey, those journeys are on different trajectories'* [C_1P_6]

12) Reliance on mainstream supply chain

The study organisation predominantly depends on mainstream, or shorter supply chains- as described by C_1P_1- for material procurement. Although this procurement strategy offers practical benefits, such as greater control, it can significantly hinder the adoption of PwRC. Indeed, this limited pool of suppliers may struggle to provide a diverse range of PwRC that meet the requirements.

> *'We use mainstream suppliers, Armstrongs, the Tarketts, the Polyflors and those kinds of things. So, if a fourth player were to enter into the market, maybe a smaller player, but maybe had a higher recycled content, and even if they were cost competitive, that would be a challenge to replace that in, because it becomes a company decision and rather than a project-specific decision if you like'* [C_1P_1]

> *'So what I mean by a shorter supply chain is, if we have an established supplier who holds stock, who we deal with very well, we already have the correct payment terms and all that other kind of stuff'.* [C_1P_6]

> *'In terms of the materials purchased and procured to manufacture new products and to maintain old products, what I found with ATCO is that they've got very long-standing relationships with suppliers that they've managed over years and years and years and moving away from those—and they've got great cost control because of that—and investigating new is where they haven't really had procurement focus'* [C_1P_5]

> *'So, you know, that is the main challenge for them around accessing the required spread of materials that they would use from suppliers who have high recycled contents, and they don't have the ability to switch those out'* [C_1P_6]

13) Varying PwRC specs in modular construction

It is a fact that sometimes the application requirements vary between modular and standard construction. As such, the PwRC suppliers need to meet varying requirements for the same material if they want to be engaged in both modular and standard construction markets. Two participants raised their concerns about this issue:

> *'Determining its fit for purpose, particularly within the module of building space where sometimes the parameters extend beyond, what we'd say, traditional building materials where I've got to worry about things like. So things like say calcium silicate board is very good in traditional buildings, but you wouldn't use it in a modular building because it*

would crack. It would break unless you applied a certain glue, a certain consistency, and having, you know, you would have to alter the engineering parameters about the use of the product just to incorporate that within a modular structure' [C_1P_1]

'Like the majority of all these sales reps, "Yes, it meets the requirement of the NCC [National Construction Code]*". But when it comes to construction then, if we applied install in a separate way different way, it's not going to meet the requirements, or it was going to lose the warranty of those products'* [C_1P_2]

14) Limited reporting capacity

Both the organisation and the supply chain lack a mature infrastructure for reporting on PwRC usage. The absence of data needed for planning and decision-making in modular construction can discourage key stakeholders, including sustainability-focused clients, from using PwRC in projects.

'So sometimes we end up finding in construction, we're ticking a box without actually having any data that's usable from that, and the industry's not there necessarily learning' [C_1P_5]

'We've got limited data on the used side as opposed to the purchase side, and we're trying to get on top of that' [C_1P_5]

'How are we, what like, what recycling products are we using? How am I reporting through NGER [National Greenhouse and Energy Reporting] *my impact on that project? So what ends up happening is they go, "Look, we still have to get you to fill it out. So just put it, just send this e-mail with the reporting template every month with zero'* [C_1P_5]

'The transparency of waste diversion ratios is the harder part because each individual supplier of those waste services will have different and varied levels of ability to report for us. So that's the bit that I've struggled with in the past two years, is getting consistent data to then analyse that data and set targets for improvement on diversion ratios for waste' [C_1P_5]

15) Limited capacity to integrate PwRC into production processes

Despite the organization having its own manufacturing unit, its current business model does not promote the internal integration of recycled materials into modular components. According to C_1P_5, the organisation typically purchases final products that may or may not include recycled content, a practice that appears to be standard across the industry. This approach significantly limits the potential to optimise the use of PwRC in modular construction, as it hinders the organisation's ability to directly influence and incorporate sustainable materials into its production processes.

'[We use recycled materials] *If the base material comes with that built-in, so one of the key things that I think it'll come in and one of the later questions, is that we use a such a small palette of materials'*[C_1P_1]

'Getting that as a raw product is not gonna happen for ATCO 'cause we don't necessarily use a raw product. We then use, you know, we use steel, we don't get the raw product and then blend it with steel because we don't make our own steel. We don't make our own wall panelling etc. So, we're always using the end product. So, we would never be directly procuring raw waste' [C_1P_5]

16) Short-term thinking in decision-making process

Short-term thinking in decision-making can restrict the organisation's ability to embrace innovation and change, especially in areas like the circular economy in modular construction. Given that the benefits of sustainability initiatives often accrue over the long term, transforming decision-making

processes to prioritise long-term outcomes is crucial. Some participants' responses on this issue are provided below:

> *'I guess one of the challenges with short-term thinking is that there's a cost involved to it… You know, if sustainability is #1, then yeah, we're looking great. However, if the price is #1, then those options can look quite expensive in the short term'* [C_1P_4]

> *'The issue is that we haven't made up a decision yet because it's more like a salesperson walk in… we're kind of looking to other what other competitors are doing at the moment where the other competitors are'* [C_1P_2]

5.5 Drivers of using PwRC in modular construction

The analysis of interviews showed that there could be six major drivers for using PwRC in modular construction. These factors are illustrated below.

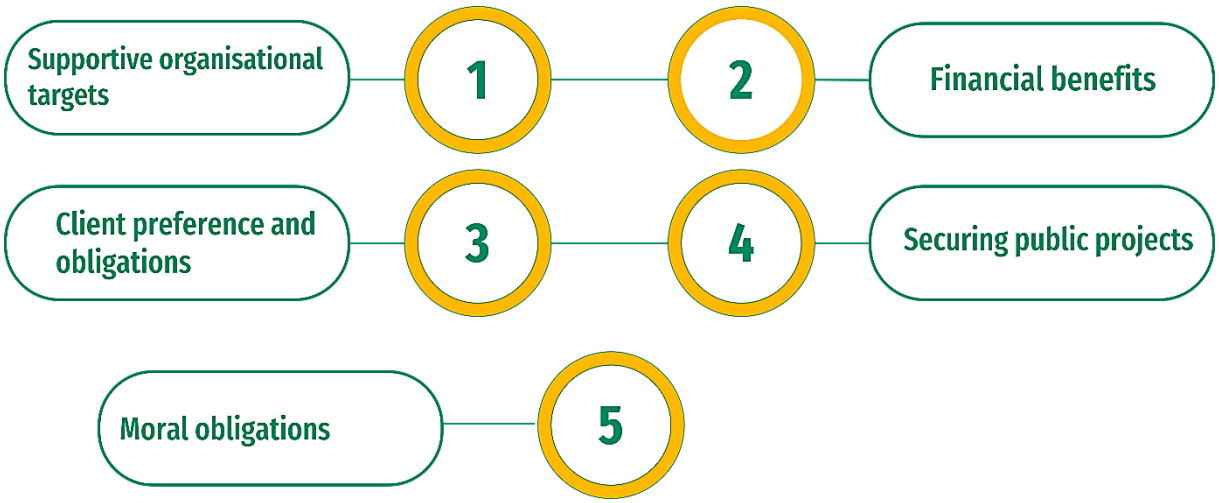

Figure 11. Major drivers for using PwRC in the case study

1) Supportive organisational targets

The incorporation of PwRC into modular products can be influenced by organisational targets/KPIs. These targets catalyse the required change in the organisational procurement model.

> *'We've got a corporate sort of structure and sometimes, shall we say, mandates certain targets. So some of those targets get driven down into obviously managing directors and you know the director of the various business groups…so some of that decision-making can be KPI-driven in terms of we must now start to use this, if that's the directive, you know, we must reduce waste by this amount or increase utilisation of renewables by this amount and those kind of things* [C_1P_2].

> *'The main motivators for us, though, our opportunities on the supply side to, you know increase circularity to drive that economic and social return through diversion from landfill, the reduced greenhouse gas emissions* [C_1P_6].

2) Financial benefits

The other motivating factor relates to whether these materials generate any financial benefits. According to the interviews (*C_1P_2, C_1P_2 and C_1P_4*), this factor can be a significant change facilitator in the decision-making process. However, these criteria vary depending on the material. For instance, the recycled alternative in steel is generally more cost-effective than in timber products. Furthermore, the long-term financial benefits of utilising these resources can be realised by integrating the reuse of waste materials into standard business practices. Over time, this will lead to a reduction in production and operational costs (*C_1P_4*).

'So the decision-making, particularly when it comes to using products with recycled content it either typically driven by a new product being profitable to the company' [C_1P_2].

'If you take a long-term stance as the business, quite often, a recycled product makes financial sense in the long term… Over time, it is actually a lot cheaper because there is no continued wastage and labour involved in redoing the same thing over and over again' [C_1P_4].

3) Client's preference and obligations

The third factor relates to the client's preference for using PwRC. This inclination may stem from their need to showcase their sustainability commitments, whether by reporting to public agencies, aiming for formal recognition through a sustainability rating system, or publicly promoting their dedication to sustainability. The client's preference typically is translated into contractual obligations. In this space, the government plays a key role in pushing a sustainability agenda including using PwRC in their assets and construction projects.

'Some of our, shall we say, bigger clients, particularly in the mining and resource sector, they have global minimum standards, and they want full material traceability and that kind of things, and that pushes you down a certain supply chain, if you like'. [C_1P_1]

'Basically, we received a lot of requests from education tender…But yeah, predominantly the education sector across Australia is the driving force behind introducing new recycled materials. It's all about that, helping the environment and things like that [C_1P_2]

'Really it comes down to contractual obligations, we rarely find a cheaper cost alternative with recycled products, I guess in application to our buildings I would say' [C_1P_3].

'Whereas tier one builders they, you know, report to the government, they're doing government work so they are held commercially to these standards…like a Green Star checklist that they would have to fill out, which says, "how do you do this? How do you do that? "In which case, they would need to engage sustainable materials or practises to be able to tick those boxes' [C_1P_4]

'So what it is that a customer needs as part of their contractual requirements or obligations from their customers as well… contractual obligations generally, or often, on government projects, be they transport infrastructure projects that drive requirements for very high recycled contents across all materials.' [C_1P_6].

4) Securing public projects

In some cases, the client for ATCO S&L products is the government which is typically in favour of enhancing sustainability in their procurement (C_1P_4). The growing demand for environmentally sustainable practices, including the use of green materials in government construction projects, is a significant driving force behind the adoption of PwRC in modular construction.

'We have received a couple of requests [tender documentation] *from especially education, and they introduce, and I've seen a couple of new materials being introduced to get on to it, to get a quote or design based off those materials'* [C_1P_2].

'It definitely ticks a box for a lot of government jobs. So we need to be playing in that space because otherwise, you know, if we're not being sustainable, we're not using recycled materials, it could be the difference between us winning and losing a job. So we want to make sure that we're putting ourselves in the best position to win these jobs as possible' [C_1P_4].

'*I would call it a regulatory role, in terms of the major rating tools and a regulatory role in terms of any particular government or other organisations that provide or drive the*

sustainability requirements… transport infrastructure projects that drive requirements for very high recycled contents across all materials' [C_1P_6].

5) Moral obligations

The final factor pertains to the moral imperatives and ethical considerations that drive individuals to adopt sustainable practices. According to three participants (C_1P_1, C_1P_4 and C_1P_5) in the organisation, staff would like to push the sustainability agenda: *we do still have a personal obligation as human beings to try and do our best to make sure that we're not overusing things that we don't need to. So, there's a moral obligation there*' [C_1P_4].

'It's just business and there is an ethical aspect that you need to consider when you're, making those decisions, it can never be just business' [C_1P_1].

'Like any person, we know that as a society and as the population continues to increase and we continue to use more and more of the raw natural resources of Earth, we're going to have to get better at recycling and we're going to have to get better at reusing recycling' [C_1P_5].

5.6 Strategies to optimise the use of PwRC in modular construction

The next section of the interview focused on strategies to effectively remove or minimize the challenges associated with utilising PwRC in modular construction. The analysis of interviews identified 10 major strategies that companies involved in modular construction in Australia can employ to increase the uptake of PwRC in their products. These strategies fall into three key domains: organisational capacity building, supply chain management assessment and improvement, and sustainable business decision-making.

Among these, the categories of "attitudinal changes and awareness raising" and "internal opportunities for material recyclability and reuse" were found to have the most significant positive impact. The identified categories are illustrated in Figure 12.

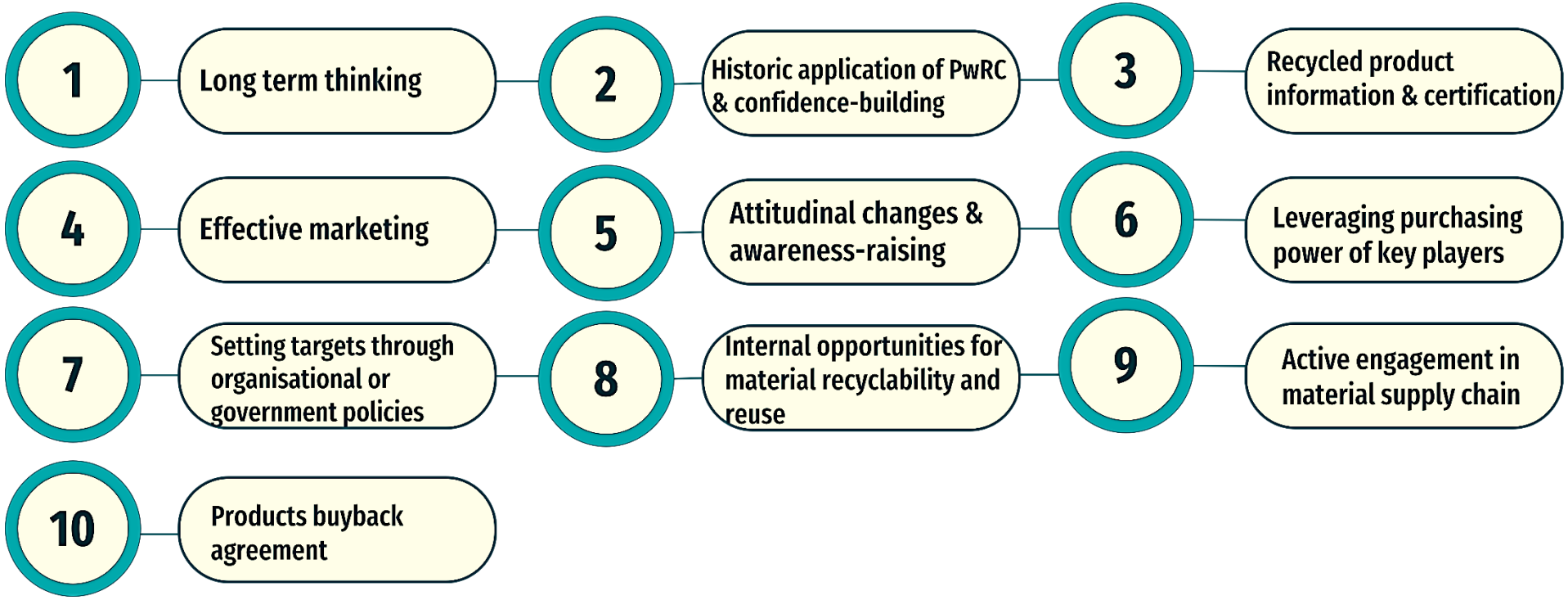

Figure 12. Strategies to enhance the use of PwRC in modular construction

1) Long term thinking

The long-term thinking approach involves planning and deciding with a focus on future outcomes rather than just immediate benefits. At present, the use of PwRC does not necessarily yield immediate economic benefits, with both potential and tangible advantages often materializing only over the long term. Therefore, organisations in the modular construction sector aiming to enhance sustainability and achieve their business objectives must adopt long-term thinking in their decision-making processes, particularly when it comes to incorporating PwRC into their products. This point was made by C_1P_4 who suggested that long-term thinking is the key to success:

> *'These days, a lot of businesses are making a lot more, especially ATCO, long-term decisions as opposed to short-term decisions within the business to ensure that we're doing the right things to put us in a good frame coming into the next five, 10, 20 years'* [C_1P_4].

> *'In the first instance, it* [PwRC] *is more expensive than what we're currently doing. However, over time, it is actually a lot cheaper because there is not the continued wastage and labour involved in redoing the same thing over and over again … so there was actually a business motive there to, you know, increase our profits, I guess, at the end of the day, over the long term'* [C_1P_4].

> *'The economic, I think we've talked about that, which is the fact that a lot of these recycled products have a longer life span than the other ones. So, whilst they may be a higher initial investment, they certainly provide better economical advantages over the long term'* [C_1P_4].

2) Historic application of PwRC and confidence-building

The successful application of PwRC across the industry can significantly boost confidence in utilising these resources. Two participants in this study emphasised that their organisation would be more likely to adopt PwRC in their products if these materials had been used in real-life projects and relevant data were available. Creating demonstration modular projects where the study organization successfully integrates PwRC offers a unique opportunity to lead the market and set a precedent in this area.

> *'If this product's being used, if there's a positive historical background of this product being used by the industry then, and it's cost effective, then the company will go down into that line'* [C_1P_2].

> *'for ATCO in particular, to move into looking further at recyclable materials in their manufacturing space, one of the things that would make it easier is having that information available to be more readily presented rather than having to do their own digging and investigation'* [C_1P_5].

3) Recycled product information and certification

Three participants noted that certified information on PwRC can inform their procurement process. However, the effectiveness of this process can be hindered by the existence of various certification schemes and different product information. To address this, the organisation should develop new or utilise existing standard templates to ensure consistent and reliable product information is received. In this process, consulting with trusted third-party PwRC certifiers and major suppliers is essential. Such a template should outline the product's features (such as physical and chemical characteristics) as well as its functions (including quality, longevity, and performance). The template must align with sustainability reporting requirements, including Green Star, IS rating, LEED, and NGER. According to C_1P_2, the product information should be prepared and produced to demonstrate their conformity with NCC.

'So whether they [PwRC] *are fit for purpose and those kind of things, so I usually get when a salesman comes in. I don't necessarily speak to the salesman, but I will speak to the data that they provide or don't provide'* [C_1P_1].

'Some sort of reuse of recycling materials and it should come with evidence, producing evidence that these products have been tested on the market and there's some companies, that they're doing all series of testing and certificates of conformance that it meets the requirements of the NCC' [C_1P_2].

'It's very easy to get the upfront cost analysis, it should be easy [to use PwRC] *if the provider of a recycled product has all that information around their product'* [C_1P_5].

4) Effective marketing

Being able to communicate the sustainability practice of the organisation can offer a series of benefits. According to C_1P_5 these benefits may include having a positive return on the business and more clients would like to work with the organisation compared to their competitors. Sustainability is a key selling point for businesses in the current and future industry climates. The use of these products in modular construction can be aligned with many sustainability initiatives including Environmental, social, and governance (ESG) and Sustainable Development Goals (SDGs); Reporting the achievement of these goals, along with promoting the improved organisation's socio-environmental profile through targeted marketing tools, can enhance visibility across industry, government sectors, and the general public. This increased visibility can lead to greater customer reach, stronger brand recognition, and enhanced credibility within the market.

Effective marketing strategies are essential for achieving the best outcomes. These strategies should communicate and highlight the journey behind the use of PwRC, the organisation's achievements, and the benefits they offer, ensuring maximum visibility and impact.

'You can offset cost for cost, if we can then also demonstrate how we can market it and ATCO's not a big marketer, a self-marketer in the industry. We need to, you know, one of my tasks […] is to drive more marketing. Even if that's B2B marketing for ATCO structures in Australia, one of those things is we need to get better at marketing and that's where having improved ESG is a marketable thing for every business in Australia moving forward' [C_1P_5].

'To be able to lead it, from a marketing perspective, from a global perspective and show how good we can be in this, what prevents me from doing that, it's really good business case to say we can produce buildings at the same rate and the same volume that we're doing, so with these products, these products are better for the environment because they are recyclable' [C_1P_5].

'We can present that, we can be proud of that and that's going to actually have a positive return on our business because more and more people will want to work with ATCO rather than with one of our competitors. So I, yeah, absolutely look at it and we should be kicking the door down in this space' [C_1P_5].

5) Attitudinal changes and awareness-raising

Several challenges highlighted in Figure 10 can be effectively addressed with this strategy. In particular, it can help overcome the industry's conservative approach and short-term thinking in decision-making. By raising awareness among key stakeholders about the potential and actual benefits of using PwRC, this strategy can accelerate the procurement and application of these products in modular construction projects.

'But I think if, everyone understands the nature and the concept behind the using of recycled materials, I think, it can change the methodology, it can change the mindset, especially who's driving the construction' [C_1P_2]

'Yeah, I think probably increased knowledge and awareness around particular products would be key. Understanding how it would benefit our processes and our methodology construction methodology in modular. I think largely people would be happy to entertain using recycled products as long as we understood the benefits, better understand' [C_1P_3]

'It's more getting the big players in the modular industry, like we said earlier, to change their mindset so that they can accept like for like, or not like for like, but like for different with a better outcome' [C_1P_5]

'It's being able to present all the answers to them [senior managers in modular construction companies] *before you even ask them to look at it, is the key driver for success for me'* [C_1P_5]

6) Leveraging the purchasing power of key players

Key players in the modular construction industry, such as ATCO S&L, possess significant influence to make the use of PwRC a standard practice across the sector. As market leaders, these companies should focus on building internal capacity to effectively procure and integrate PwRC into their products. Once these practices are established as the industry norm, it will encourage SMEs to adopt similar procurement strategies, further embedding PwRC use in the industry. According to C_1P_4, their purchasing power can generate sustainable demand for these products, potentially leading to economies of scale and a reduction in production costs. The organisation and the recycling industry can capitalise on the advantages of mass production, leading to enhanced profit margins.

'If the big companies are not pushing and being part of the strategy, then it's never going to work. It's never going to work [C_1P_3]

'ATCO's a big company, we have a lot of buying power. You know, we could start to look at creating partnerships with companies who sell the products that we require for sustainable or recycled materials so that we can look to get better buying power and therefore create a lower price point for our clients' [C_1P_4]

7) Setting targets through organisational or government policies

Setting targets for using recycled content in products can guide processes involved in the procurement and application of PwRC in construction projects. Reasonably set targets can drive numerous changes within organizations, including fostering innovation, promoting accountability, building market demand, and encouraging collaboration across material supply chains. According to C_1P_3, the government can play a pivotal role in setting these targets by developing policies such as sustainable procurement guidelines.

'We've got a corporate sort of structure and sometimes that […] mandates certain targets. So some of those targets get driven down into obviously managing directors […]. So some of that decision making can be KPI-driven in terms of we must now start to use' [C_1P_1]

'I think it would help if there was a push, potentially from the government as well…They don't currently have any policy around using recycled material, they don't tend to' [C_1P_3]

'Both from an initial, you know, what are we doing right now? Where's my benchmark? Where's my baseline in that? And then to be able to sit there and go, OK, there's a massive opportunity to lead in this space, rather than to follow' [C_1P_5]

8) Internal opportunities for material recyclability and reuse

Organisations in modular construction can plan for maximum recyclability and reuse by incorporating these considerations throughout their manufacturing, operation and execution phases. Such incorporation can be more effectively implemented through adopting a circular economy business model. This way they can influence their internal stakeholders to advance the circularity of their products. Almost all participants in this study emphasised the importance of exploring opportunities to capture the value of waste resources and enhance the utilisation of PwRC in modular construction. For example, C_1P_1 and C_1P_4 stressed the need to revisit their production line to evaluate opportunities for material recyclability and reuse. Similarly, C_1P_6 noted that their organisation aims to recapture product waste resources for repurposing and reuse through extended producer responsibility practices.

> *'Simple builds are able to be reused and we try, we sell on that as well. We sell on the fact that we can actually bring those back into the mainstream with very little in the way of upgrades and most of those are cosmetic and those kinds of things'* [C_1P_1]

> *'So, what we try to do there as much as possible and where possible is reuse certain materials. So, for example, our decks, we have steel framed decks…So we will take that part off the deck. We will throw that part out. But we will reuse the deck frame, reline it so that we don't have to continually go and get more steel framing built for our jobs'* [C_1P_4]

> *'But I think ATCO is also going to try and match that wherever we can and where it makes sense in our product lines so that we're providing it as a standard as opposed to on a job-by-job basis'* [C_1P_4]

> *'Now, they* [low-grade polyply wall linings]*'re great. They're cheap. They go up. If a client damages it, you just unscrew it, you put a new sheet up. So being able to look at recyclable materials of that and in effect, it already is recyclable to an extent'* [C_1P_5]

> *'it's not so much the need for modular to look at how do we generate a product in the first place? It's what products are out there, and how do we use them in our existing processes? it's not that the products and the research isn't already out in the market for recyclable, it's, "OK, where can we use this in the modular game"* [C_1P_5]

> *'So as a business that is very much our focus from a point of view of maximising recycled content and then the idea of keeping that in, through its use phase and then to its end-of-life phase and then recapturing that back through our recycling business or indeed any of the other recycling channels or reuse opportunities to bring that back into as a new product or as a reused product to keep that loop going'* [C_1P_6]

9) Active engagement in the material supply chain

Modular construction companies should actively engage in the material supply chain to influence their external stakeholders to achieve material circularity outcomes. Changes within the supply chain should focus on waste reduction, increased utilisation of recycled content, and the enhancement of PwRC quality, longevity, and performance. According to C_1P_4, these changes should stem from strategic partnerships with material suppliers involved in PwRC production and supply.

> *'Re-recycle it into our own product, if you like. So, if we had a closed-loop supply chain in terms of, say, the vinyl manufacturer…if you had a supplier of material down the road where, you know, the off-cuts could be taken straight back, put in a hopper, chopped up and then used to produce the same material again'* [C_1P_1]

> *'So, get me stillages that can be reused if they, if a client says they can't. Or a supplier says they can't supply it in the correct packaging to be reused. Then you send the packaging back with the next truck when they deliver'* [C_1P_1]

'You know, we could start to look at creating partnerships with companies who sell the products that we require for sustainable or recycled materials so that we can look to get better buying power and therefore create a lower price point for our clients' [C_1P_4]

'Is there other things that you can blend into it like I was talking about? You know, microplastics. Can we get microplastics? … Is there a potential way to actually blend those plastics from a container bottle scheme into the timber product with the bonding agents so that you've got a semi-waterproof product that then has a higher lifespan, and therefore we're not replacing it as frequently' [C_1P_5]

10) Products buyback agreements

The final strategy involves creating contracts that explicitly stipulate a product buyback agreement between modular manufacturers and end-users. Given that modular products are not always used permanently, a buyback arrangement provides an opportunity for manufacturers to repurchase these items from end-users. According to C_1P_1, this agreement offers mutual benefits: end-users can generate revenue by selling unused products, while manufacturers gain the opportunity to recover modular products either fully or partially. The materials salvaged from these end-of-life modular products can then be repurposed in new modular builds, promoting sustainability and resource efficiency.

'So sometimes we will sell a building with a buyback in there because we are better able to reuse and repurpose that building. The clients might have it for 5- 10 years and it's not economical for them to rent it for that period of time, but it is economical for them to buy it, and then we will buy it back from them for an agreed price' [C_1P_1]

5.7 The future of PwRC applications in modular construction

The interviewees suggested that a broader application of PwRC in the modular construction industry is plausible in the future. However, several participants emphasised the necessity of specific changes for this to materialise. These changes include overcoming the sector's conservative approach, its mindset transformation, preparing for a transitional phase, and achieving greater adoption within the conventional construction sector. Table 5 presents the key points highlighted by participants in response to this question.

Table 5. Participants' views regarding the future of PwRC applications in modular construction

Participant	Key point	Quote
C_1P_1	Challenges posed by sector conservatism	*I think the future applications of recycled materials will be in new product development because the construction industry, by its nature, is very conservative. But, like I said, a lot of things are based on, "It worked last time. I will do it again". And so, you always end up with a 'It's almost like a generational change'*
C_1P_2	Initially complex, ultimately ubiquitous	*I think it can be complicated for a start, but then for certain period of time in that transition period, I think everyone will start picking up and say, "OK, yeah, it's worth going with recycle*
C_1P_3	Mainstream upon sector's adoption	*If there's a place for recycled material in construction, there's probably no problem in a ship to modular construction to utilise those projects, those products*
C_1P_4	Expanding with growing PwRC development	*I think it's only gonna get bigger and bigger, personally. More and more products are being delivered and created with recycled materials*
C_1P_5	Dependent on the industry mindset transformation	*It's not so much the need for modular to look at how we generate a product in the first place? It's what products are out there, and how do we use them in our existing processes? It's more getting the big players in the modular industry… to change their mindset so that they can accept […]like for different with a better outcome.*
C_1P_6	Growth driven by urban development needs	*As countries and as cities develop, that supply chain of recycled material increases because you put it in once and as you redevelop, rip down, repair, rebuild, that steel comes back out and into the recycling channel*

5.8 A framework to enhance PwRC uptake in modular construction

The following model is created based on the findings' literature review presented earlier and the insights captured in the interviews. The framework guides efforts in removing the identified obstacles to sustainable and optimal uptake of PwRC in modular construction. As outlined in Figure 13, the framework consists of organisational capacity, supply chain, recycled products and regulations and policies major components that address various obstacles identified in this study.

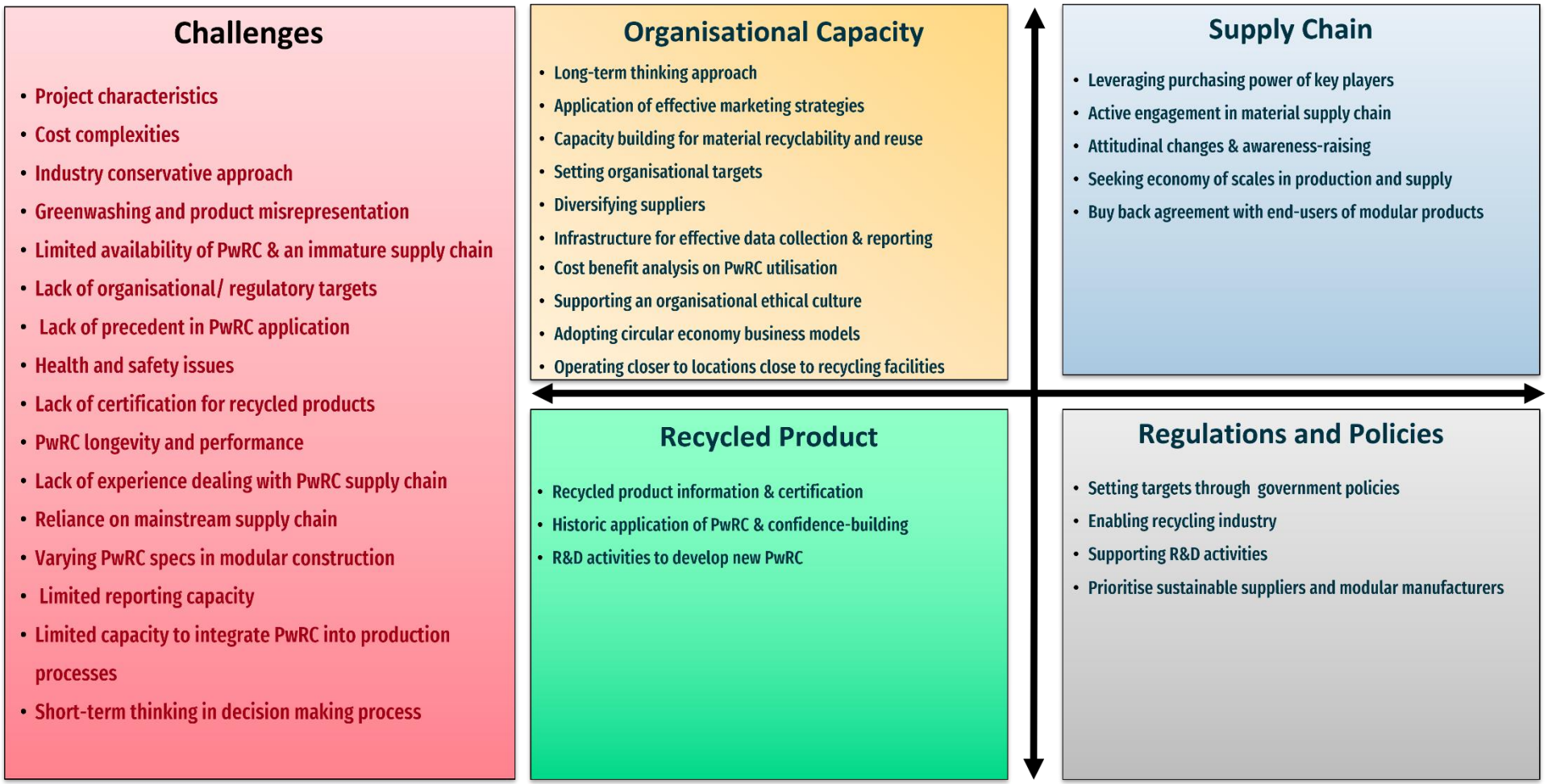

Figure 13. A framework to influence stakeholders for optimal uptake of PwRC in modular construction

6 RECOMMENDATIONS

ATCO S&L may consider adopting the strategies outlined in the framework to enhance its capacity for increasing the uptake of PwRC in its offerings. The organisation can also lead and influence the supply chain by implementing the tools and strategies proposed in this study, making the use of PwRC a standard practice. To achieve this, the organisation should plan for a gradual implementation of these strategies, aligning them with their priorities and business objectives.

Currently, many Australian governments are under pressure to meet the requirements of the SDGs and various climate change initiatives, such as the Paris Agreement. Government agencies involved in the sustainability of built environments and construction activities can leverage the findings of this study to evaluate, plan, and prioritize the most effective actions to enhance sustainability outcomes moving forward.

The building and construction sector should pay close attention to the modular construction space, as it is increasingly being proposed as a viable solution to housing crises both in Australia and globally. The challenges identified in this study can help the industry prepare for a transition towards more modular and sustainable buildings in the near and distant future. Thus, the sector has an excellent opportunity to reduce its environmental impact by incorporating PwRC in modular building products.